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Seasonal evolution and interannual variability of the local solar energy absorbed by the Arctic sea ice–ocean system

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[1] The melt season of the Arctic sea ice cover is greatly affected by the partitioning of the incident solar radiation between reflection to the atmosphere and absorption in the ice and ocean. This partitioning exhibits a strong seasonal cycle and significant interannual variability. Data in the period 1998, 2000–2004 were analyzed in this study. Observations made during the 1997–1998 SHEBA (Surface HEat Budget of the Arctic Ocean) field experiment showed a strong seasonal dependence of the partitioning, dominated by a five-phase albedo evolution. QuikSCAT scatterometer data from the SHEBA region in 1999–2004 were used to further investigate solar partitioning in summer. The time series of scatterometer data were used to determine the onset of melt and the beginning of freezeup. This information was combined with SSM/I-derived ice concentration, TOVS-based estimates of incident solar irradiance, and SHEBA results to estimate the amount of solar energy absorbed in the ice-ocean system for these years. The average total solar energy absorbed in the ice-ocean system from April through September was 900 MJ m^{-2}. There was considerable interannual variability, with a range of 826 to 1044 MJ m^{-2}. The total amount of solar energy absorbed by the ice and ocean was strongly related to the date of melt onset, but only weakly related to the total duration of the melt season or the onset of freezeup. The timing of melt onset is significant because the incident solar energy is large and a change at this time propagates through the entire melt season, affecting the albedo every day throughout melt and freezeup.

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1. Introduction

[2] The Arctic sea ice cover may be a sensitive indicator and a potential amplifier of climate change [*Dickinson et al.*, 1987; *Moritz et al.*, 1993; *Jin et al.*, 1994; *Rind et al.*, 1995; *Battisti et al.*, 1997; *Serreze and Francis*, 2005]. Numerous studies have demonstrated that the Arctic sea ice cover has been undergoing significant changes for the past few decades, with a reduction in the amount of multiyear ice [*Johannessen et al.*, 1999; *Comiso*, 2002], decreases in ice extent of 3% per decade [*Parkinson et al.*, 1999; *Parkinson and Cavalieri*, 2002], and an overall thinning of the ice [*Rothrock et al.*, 1999; *Tucker et al.*, 2001].

[3] A key element in determining the causes, and the potential implications, of these changes is understanding the interaction of solar radiation with the ice cover. Melting is strongly affected by the partitioning of solar radiation between reflection to the atmosphere, absorption in the ice, and transmission to the ocean. This partitioning, in turn, is influenced by the timing and duration of the melt season. Of particular importance is the amount of solar energy absorbed by the ice-ocean system. This is the essence of the ice-albedo feedback, which is a powerful mechanism connecting the ice cover to the climate system.

[4] The surface heat budget of the Arctic ice cover and the ice-albedo feedback were studied in detail during the SHEBA program [*Moritz et al.*, 1993; *Perovich et al.*, 1999; *Uttal et al.*, 2002]. This program entailed a year-long field experiment plus an extensive data assimilation and modeling effort. Analysis of the field results provided considerable insights on the surface heat budget [*Persson et al.*, 2002; *Andreas et al.*, 2002], the ice mass balance [*Perovich et al.*, 2003], and the ice-albedo feedback and solar partitioning [*Curry et al.*, 2001; *Perovich et al.*, 2002a; *Perovich*, 2005]. The field observations made at one location for 1 year were generalized through a modeling effort that examined the underlying processes governing the surface heat budget.

[5] With only 1 year of observations, SHEBA did not investigate the interannual variability of solar partitioning. It did, however, provide a conceptual framework for such a study. In particular, during SHEBA the seasonal evolution

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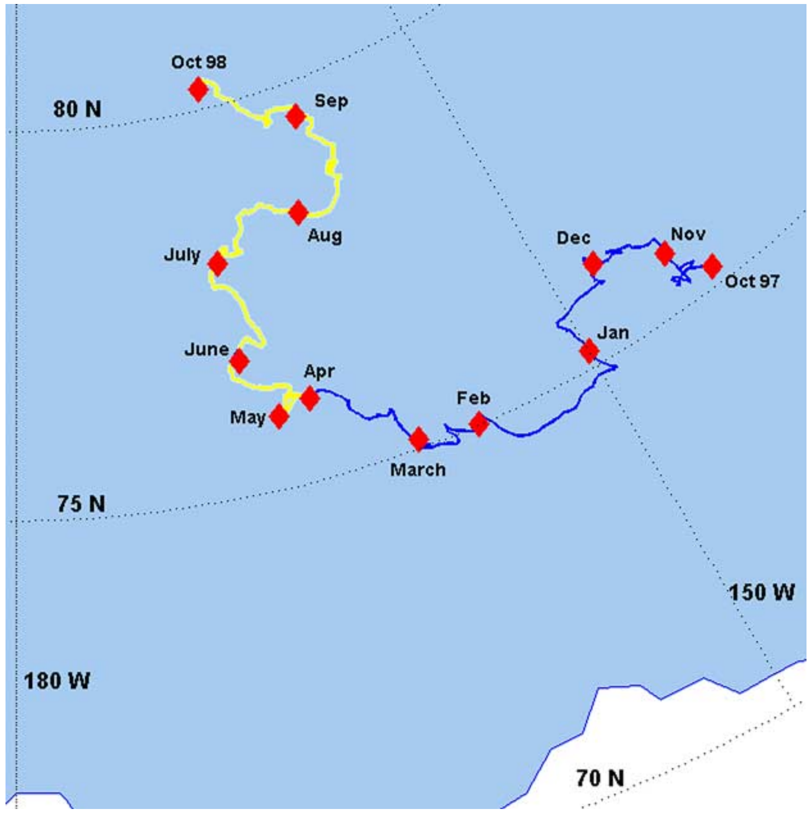

Figure 1. Drift of Ice Station SHEBA from October 1997 to October 1998. Our interest focuses on the period from April through September 1998 (in yellow).

of albedo was strongly influenced by the onset of melt and freezeup. For studies on the regional to Arctic Ocean scale, wide-swath satellite data are invaluable. In this study, we applied active microwave data collected by the SeaWinds scatterometer aboard the QuikSCAT satellite (denoted as QSCAT hereon) to determine the timing of melt onset and fall freezeup from 2000 through 2004 for the region where the SHEBA field experiment took place. We then combine this information with SHEBA results and Special Sensor Microwave/Imager (SSM/I) and the TIROS-N Operational Vertical Sounder (TOVS) Polar Pathfinder satellite observations to examine the interannual variability of solar partitioning.

4. Conclusions

[39] Observations from the scatterometer on the QSCAT satellite can provide the dates of melt onset and fall freezeup. When coupled with information on ice concentration and the existing observational data set of albedo evolution, estimates of the amount of solar energy absorbed by the Arctic sea ice cover can be calculated. The solar energy absorbed by the ice and ocean displays a strong seasonal trend, with peak values occurring between mid-June and mid-July, as well as significant interannual variability. Over the 6 years studied (1998–2004), the total solar energy absorbed by the ice-ocean system ranged from 850 to 1100 MJ m^{-2}. The solar energy absorbed depended much more strongly on the timing of the onset of melt than with the total incident solar energy. These differences in solar energy absorbed could result in interannual variations in ice ablation of tens of centimeters per year. Years with large solar energy absorbed appear to be correlated with reduced ice extent. The total solar absorbed is more strongly related to the timing of the onset of melt than to the onset of freezeup or the duration of melt. Stated simply, a day of melting in the spring has a much greater impact than a day in late summer. Each day melt starts earlier increases cumulative solar energy absorbed by about 8.7 MJ m^{-2} (~3 cm of melt) while a 1 day delay in freezeup only increases the cumulative solar energy absorbed by about 1.5 MJ m^{-2} (~0.5 cm of melt). This is a direct consequence of the larger values of incident solar energy in May and June and the cumulative impact over the entire melt season of a change at the beginning. The impact of date of melt onset on total solar input suggests that storms and warm air masses in late spring may have great influence by triggering the onset of melt [*Bitz et al.*, 1996]. The next step in this effort will be to extend this analysis to the entire Arctic Basin, providing a large-scale examination of the changing solar energy absorbed by a changing ice cover and its impact on Arctic ice mass balance.